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ABSTRACT

Compiled from interviews with personnel in pulmonary function testing (PFT) laboratories in the Minneapolis/St. Paul area, this competency-based curriculum guide is intended to provide a knowledge of PFT for persons who provide respiratory care. The guide contains 20 sections covering the following topics: vital capacity, flow measurements, spirometry, residual volume, arterial blood gases, diffusion testing (single breath and steady state), closing volume (delta nitrogen), flow-volume loops, volumes of isoflow, mechanics testing, p50 measurements, Fick cardiac output and respiratory quotient, VD/VT, oxygen and carbon dioxide response, occlusion pressures, computerization, methylcholine (allergen challenging), sleep apnea testing, and pulmonary stress testing. Each section contains objectives, a prespective on the procedure equipment and subject preparation, calculations, and self-checking questions. Answers to the questions are found at the back of the guide, along with normal test levels and references. (KC)

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ED232001

CARDIO-PULMONARY FUNCTION TESTING

Continuing Education Curriculum for Respiratory Therapy

State Contract No.: 7-CO-80/MN-80-94-482-1-07-CO-133

Respiratory Therapy Program

St. Paul Technical Vocational Institute

St. Paul, Minnesota

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Continuing Education Curriculum for Respiratory Therapists. St. Paul TVI

SECTIONS

1. Vital Capacity
2. Flow Measurements
3. Spirometry
4. Residual Volume
5. Arterial Blood Gases
6. Diffusion Testing - Single Breath
7. Diffusion Testing - Steady State
8. Closing Volume - Delta Nitrogen
9. Flow-Volume Loops
10. Volumes of Isoflow
11. Mechanics Testing
12. p50 Measurements
13. Fick Cardiac Output and Respiratory Quotient
14. VD/VT
15. Oxygen and Carbon Dioxide Response
16. Occlusion Pressures
17. Computerization
18. Methylcholine - Allergen Challenging
19. Sleep Apnea Testing
20. Pulmonary Stress Testing

PREFACE

Pulmonary Function Testing is the diagnostic branch of practicing respiratory care. The association between Pulmonary Function Testing (PFT) and respiratory care has been confusing. In many institutions, there has been an overlap of tasks performed in the clinical setting and those performed in the PFT laboratory. Since respiratory care practitioners and students must have knowledge in both areas, this manual will attempt to remedy frequently stated deficiencies in Pulmonary Function Testing. This manual is in the spirit of application or competency-based education in that each section will contain objectives, a performance analysis, calculations when necessary and a brief exam. The manual's purpose is not one of instruction in anatomy and physiology or PFT interpretation, but a perspective on each procedure was felt to be necessary.

Equipment for PF Testing must accurately measure the desired flows, volumes, pressures, etc. This manual will not advocate specific models of equipment since accurate performance is dependent upon preventive maintenance, servicing, module additions, modifications and tolerances that must be determined by the directors of the particular laboratory. Furthermore, the normals for each lab are used with that lab's particular purposes and no set of normals will be advocated. Normals used in the examples are found in Appendix A.

This manual was compiled from interviews with personnel in PF laboratories in the Minneapolis-St. Paul area and their contributions are greatly appreciated.

1. VITAL CAPACITY

OBJECTIVES

- The learner shall have the subject perform a vital capacity maneuver.
- The repeated best effort vital capacity will be recorded.
- For the subject's age, height and sex, a predicted vital capacity will be determined and a percent of predicted vital capacity will be calculated.

PERSPECTIVE

The measurement of vital capacity was initally performed on over 2000 normal men by a surgeon, John Hutchinson, in 1844. Vital capacity is measured as the largest volume blown into a spirometer from the position of maximum inspiration. Although the method of predicting one's vital capacity was argued at the turn of the century, Hutchinson's original parameters of age, height and sex are currently used. Hutchinson proposed the parameters as well as the method of repeating the test three times to be sure of repeatability and correcting the attained volume to a standardized temperature. Vital capacity is normally less in females, decreases with age and increases with height.

Vital capacity is currently used as a standard measurement for the extent of restrictive disease of which less than 80% of predicted is considered abnormal. Generally, vital capacity is reduced in three types of disorders:

1. Neuromuscular disease - i.e. Guillian Barre
2. Mechanical decrease in thoracic space - kyphoscoliosis, Ca
3. Interstitial lung disease - silicosis

An increased vital capacity can actually be of assistance in the diagnosis of obstructive disease. Vital capacity is an easily performed and calculated procedure of potentially immediate significance. It does depend on subject effort, but may, therefore, be a measure of subject effort.

VITAL CAPACITY

Equipment Preparation - The graph paper should be zeroed or centered. The spirograph may require calibrating between each use.

Subject Preparation - Obtain the subject's age and height. Explain to the subject that the test is short, simple and must be repeated. Emphasize that maximum efforts are essential. Place noseclips on the subject.

1. Instruct the subject to take as DEEP A BREATH AS POSSIBLE. Encouragement at this point will assist towards a valid test more than at any other point.

2. Have the subject blow into the mouthpiece with an airtight seal - BLOW, BLOW INTO THE MACHINE - until the breath is completely exhaled.

(2.') A slow vital capacity is performed in the same manner without encouragement to exhale rapidly but rather a slow, steady exhalation. A slow vital capacity may yield a higher value than a forced vital capacity indicating air trapping or obstructive disease.

3. Turn off the machine and have the subject rest for a minute. Compliment a good effort.

4. Repeat the procedure at least two more times until a maximum volume is repeated within 5%.

5. Calculations:
   a. Determine the subject's predicted vital capacity from their sex, height and age (appendix).
   b. Record the subject's repeated, best effort vital capacity.
   c. Correct for temperature if not done on the graph paper.
   d. Divide the subject's VC by the predicted VC and multiply by 100 to obtain a percent of predicted.

Example

Subject's VC = 3850 ml.

Temp. correction for 20 degrees C. = 1.102

Subject's predicted VC - 40 y/o female, 64 inches or 163 cm =
(.0481x163) - (.020x40) - 2.81 = 4.23 L = 4230 ml.

Corrected VC 3850 x 1.102 = 4243 ml.

Subject's VC = 4243/4230 = 100% of predicted

QUESTIONS - VITAL CAPACITY

1. Vital capacities were originally performed by _____ _____ in 1844.

2. At what percent of predicted is the vital capacity considered abnormal?

3. How many times should a vital capacity maneuver be repeated?

2. DYNAMIC VOLUMES - FLOWS

OBJECTIVES

- The learner shall instruct the subject to perform a maximum forced expiratory maneuver.
- The expired breath will be recorded on a volume/time recording device.
- The learner shall calculate the flow parameters: FEV1/FVC, PF, FEF 25-75.

PERSPECTIVE

Flow rate measurements or dynamic lung volumes are taken from three basic tests: the MVV, forced vital capacity on a volume/time device and a forced vital capacity on a flow/volume device (section 9). The concept of measuring the rate of ventilation (MBC) was described in 1933, but not until 1947 was exhaled volume plotted and referenced to time. This easily performed and calculated test has since then assisted in the determination and definition of obstructive disease or the deficiency in exhaling a lung volume (asthma, emphysema, chronic bronchitis). This pattern of forced expiratory volume is examined in detail to analyze the degree and region of airway obstruction. Specific measurements have included:

MVV - Maximum ventilatory volume in which the subject ventilates as deep and as rapidly as possible for a fixed time period (5, 10, 12 seconds). The exhaled volume in that period is accumulated and multiplied to attain a rate for one minute. The MVV can then be compared to a calculated normal for that individual and reported as a percent of predicted.

FEV1/FVC - The most valid and reliable of the flow measurements in which the exhaled volume in one second is compared to the individual's forced vital capacity. That fraction x 100 should normally be over 80%, but more than 70% is usually considered acceptable.

Peak Flow - A peak flow portion of the forced expired volume to be estimated by forced expiratory flow (FEF) 200-1200, but accurately determined by a flow volume loop. One must discard the first 200 ml exhaled and then measure the time taken for the next liter exhaled. That liter divided by the time will approximate the peak flow and can be multiplied by 60 to attain a minute flow rate. The test can be susceptible to variable patient effort.

Mid Flow - Estimated by a FEF 25-75, this portion of the exhaled volume/time has been proposed as an early measure of obstruction. At 25% of VC and 75% of VC, the time interval between them is measured. The one-half vital capacity is then divided by that time and the flow is then determined as a minute rate. Again, comparison to a predicted regression formula can give a value for obstructive impairment.

FLOWS - FEV1/VC, PF, FEF25-75

Equipment Preparation - Since volume will be measured against time, check that recording paper is centered or zeroed and that paper movement progresses.

Subject Preparation - Instruction for flow measurements is identical to the forced vital capacity test and is frequently completed with the FVC test. Use nose-clips.

1. Have the subject take in as DEEP A BREATH AS POSSIBLE.
2. Have mouthpiece air-tight sealed in subject's mouth (For a Collins, turn drum to fastest speed).
3. BLOW into the machine as FAST and COMPLETELY as possible.
4. BLOW it ALL out.
5. Turn drum off and have the patient rest.
6. Repeat the test at least two more times until maximum tracings correspond closely. Coughing, malingering, and exhaustion invalidate the test.
7. Calculations

   A. FEV1/FVC - Determine the volume exhaled in one second and divide that volume by the FVC and multiply by 100 for a value in percent. Usually, over 80% is normal and more than 70% is acceptable.

   FEV2/FEV - Determine the same except with the use of FEV after two seconds.

   B. Peak Flow - This will be more accurately determined by flow-volume loops (Ch. 10). The FVC pattern is examined closely by recording time elapsed at 200 ml and 1200 ml into the maneuver (connect and mark the spots). An overlay of slopes can allow direct reading of the PF by matching a slope with the patients and reading from the overlay. Otherwise, PF can be calculated by subtracting the 200 ml time from the 1200 ml time and dividing that time into 1000 ml (1200 ml - 200 ml). The value can then be compared to a predicted normal, multiplied by 100 and reported as a percent of predicted.

   i.e.:

	On a Collins 32mon/sec
200 ml time =	3.2 mm
1200 ml time =	9.6 mm
	6.4m/32 = .2 sec

   $$\frac{1000}{.2\text{sec}} = 5\ \text{l/sec} = 300\ \text{l/min}$$

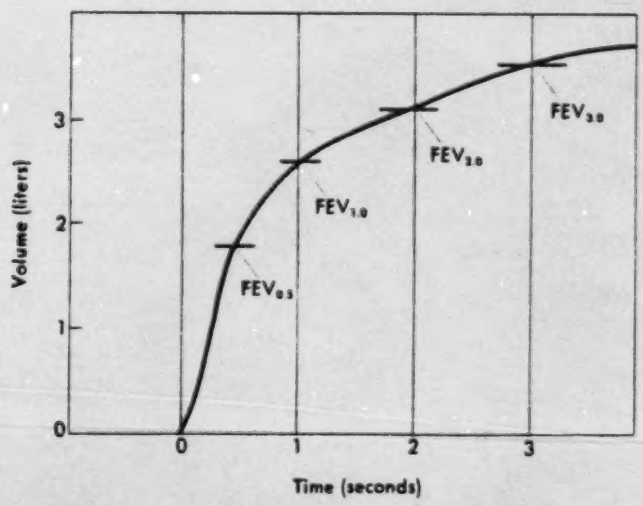
C. FEF25-75 - A "midflow" that will be more accurately measured in Ch. 10. Again, the FVC maneuver is closely examined, but at 25% and 75% of the total VC. Divide the TOTAL FVC by four and subtract that value and three times that value from the VC. Mark those two points and draw a line between them. An overlay aligned with the line of connected Marks can give the FEF25-75 or the time elapsed between the points divided into the difference of the two volumes gives the FEF25-75. Dividing the FEF25-75 into the predicted FEF25-75 x 100 can give a percent of predicted.

i.e.:	VC = 4400 ml	Time
	25% of VC = 1100 ml	.2 sec
	75% of VC = 3300 ml	.9 sec
	2200 ml	.7 sec

$\frac{2.2}{.7}$ = 3.14 l/sec = 118.4 l/m

Multiply by temperature conversion factor

*MVV - The procedure involves the subject breathing as deep and fast as possible for a fixed time period (5 sec, 10 sec, or 12 sec). The exhaled volume is then measured, usually by an accumulator, but it can be merely added or approximated by multiplying the mean VT x breaths in the time period. The attained value is multiplied to obtain a minute rate: X 12 if 5 sec, X 6 if 10 sec, X 5 if 12 sec. The MVV can then be compared to a normal and reported as percent of predicted.



QUESTIONS - FLOW MEASUREMENTS

1. Flow measurements assist the diagnosis of _____ pulmonary disease.

2. What is the most valid and reliable flow measurement?

3. Why is a midflow determination possible of more value than FEV1/VC?

3. SPIROMETRY

OBJECTIVES

- The learner shall have the subject complete spirometry studies including inspiratory capacity, expiratory reserve volume, tidal volume and respiratory rate.
- Obtain predicted normal values for the particular subject.
- Calculate the subject's percent of predicted spirometry values.

PERSPECTIVE

Tidal volume, inspiratory capacity, and expiratory reserve volume are the components of a vital capacity. A complete pulmonary function test usually includes measurement of, calculation and reporting of these parameters. Their inclusion in a complete PFT may add little more than the vital capacity towards diagnosis. Tidal volume and respiratory rate are certainly of value in monitoring the critical care patient, but their variability with emotions, activity and disease question their importance in a complete PF study. The determination of residual volume and functional residual capacity is part of spirometry testing and will be covered in the next section.

Experience has found the point of end-exhalation of a normal tidal volume to be the most consistent, repeatable position (therefore a defining position) in pulmonary function studies. The inspiratory capacity has been defined as the volume measured from end tidal exhalation to peak inspiration (at total lung capacity). The expiratory reserve volume is measured from end tidal volume to forced total exhalation (at residual volume). Normally, the inspiratory capacity (IC) is 75 percent of vital capacity while expiratory reserve volume (ERV) is 25 percent of vital capacity. These components can, therefore, be predicted from the vital capacity nomograms. Furthermore, deficits in IC and ERV would be indicative of a restrictive disease process.

BASIC SPIROMETRY

Equipment Preparation - Have equipment prepared with a CO2 absorber and for O2 addition. See that a chart recorder is performing properly.

Subject Preparation - Inform the patient that this testing period may be prolonged and requires no interruptions, but rests are possible.

1. Have the subject breath normally through the mouthpiece with lips tight and noseclips on.

2. As a pattern developes on the chart, add O2 so that a level baseline is maintained (usually 300-500 ml/min).

3. From normal tidal volume breathing, have the subject TAKE A DEEP BREATH, AS DEEP AS POSSIBLE. GOOD, BACK TO NORMAL BREATHING. From end exhalation baseline, the IC can now be determined. Repeat at least two more times for consistant results.

4. From normal tidal volume breathing, have the subject, BLOW IT ALL OUT, OUT, OUT..., GOOD BACK TO NORMAL BREATHING. From the end exhalation baseline, the volume exhaled is the ERV. Repeat at least two more times for consistant results.

5. Calculations:

   A. IC - Record values from the line of end tidal volume (A) and TLC (B).

      (B-A) x TC - Inspiratory Capacity

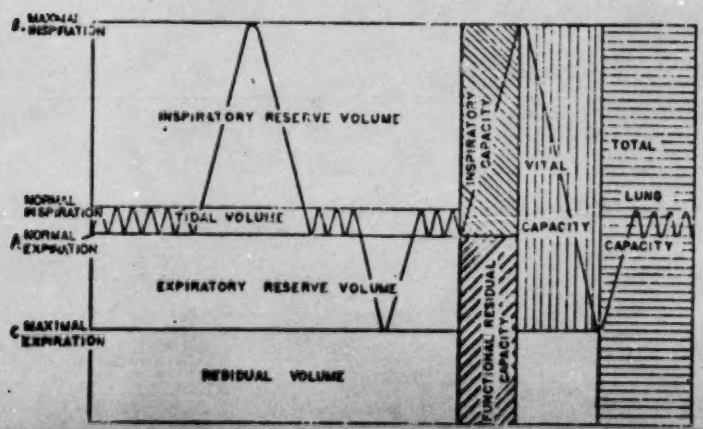
      i.e. (4800-2400)* 1.102 = 2645 ml

   B. ERV - record values from the end tidal volume (A) and FRC (C).

      (A-C) x TC = Expiratory Reserve Volume

      i.e. (2400-1200) x 1.102 = 1322.4 ml

      TC = Temperature Conversion Factor



QUESTIONS - SPIROMETRY

1. Inspiratory capacity is normally _____ percent of one's vital capacity.

2. Name three parameters of basic spirometry.

3. What is the most stable repeating position in spirometry testing?

4. RESIDUAL VOLUME

OBJECTIVE

- To have a subject perform a procedure to determine the subject's RV and FRC (ERV + RV): Helium dilution, Nitrogen washout and/or body Plethysmograph.
- Calculate RV and FRC from raw data.
- Compare calculations to predicted normals for that subject.

PERSPECTIVE

Residual volume is the volume of gas remaining in the lungs after a complete exhalation. The residual volume (RV) added to the expiratory reserve volume (ERV) defines the functional residual capacity (FRC). The RV and FRC are reduced in restrictive diseases such as pulmonary fibrosis due to silicosis, sarcoidosis or asbestosis. RV and FRC are, also, reduced but less frequently measured in the acute care setting (as in pneumonia or atelectasis). Of more importance is the increase in RV and FRC or "air-trapping" in obstructive disease. As a diagnostic tool, RV and FRC have been as much as six to seven liters in severe chronic obstructive pulmonary disease. The problem is, of course, measuring a volume that cannot be exhaled and particularly when communication to the trapped gas is impaired. The dilution of a bolus of inert gas, usually with Helium, in a closed rebreathing system can allow calculation of RV-FRC, but the dilution time can be prolonged and a CO2 absorber must be in line. RV-FRC can be measured by washing out and measuring the Nitrogen in one's lungs by inhaling 100% oxygen and capturing the exhaled Nitrogen. Over a seven minute period, this method may, also, be lengthy and does administer 100% oxygen, a possible danger to COPD patients. A third method, body plethysmography, encloses the subject in an air tight box and involves measuring airway pressure changes plotted with box pressure changes allowing a Boyle's law calculation of RV from the slope of the closed shutter attempted ventilation excursion. This method takes five seconds and measures all thoracic gas, even non-communicating airways.

FRC

A. Helium Dilution

Equipment Preparation - Calibrate and zero the Helium analyzer. See that CO2 absorber has crystals. Fill the drum/bag with a recorded volume of a Helium mixture (CI - about 10%) and analyze the mixture. Check the O2 tank for adequate pressure. Add two liters of air as measured on spirograph and analyze (C2).

Subject Preparation - Inform the subject that the test will take several minutes and that any leaks will invalidate the test. Otherwise, the procedure is fairly easy and requires only a normal breathing pattern.

1. Begin the subject breathing on the mouthpiece, valve open to room air. See that noseclips are secure and that there is no leak around the mouthpiece.

2. At an end exhalation, open the valve to your Helium mixture to begin the test.

3. Insert O2 flow test at about 200 to 500 ml/min to amount necessary for a stable baseline.

4. Assure the subject as the test progresses.

5. Observe the Helium analyzer as the diluted volume concentration stabilizes.

6. Some require a seven minute test, but stabilization of the Helium percent analysis usually indicates complete dilution. Record that He% (C3).

7. Close valve and disconnect the subject.

8. Calculate FRC.

$$FRC = \frac{C1}{C3} \times \frac{C2-C3}{C1-C2} \times \left(V \text{ air added} \times TC\right) - \left[25\text{-}100 \text{ ml} - \text{Switching deviation from baseline}\right]$$

TC = Temperature Conversion Factor

B. N2 Washout

Equipment Preparation - Have the O2 tank set up with the system containing 100% up to the patient connection (or use a demand valve). Calibrate and set the N2 analyzer to approximately 78%. Set up the system to collect and measure exhaled volume (Tissot Spirometer).

FRC - N2 Washout
(continued)

Subject Preparation - Again, inform the subject that the test takes several minutes and that "no leaks" are essential.

1. Have the patient breath through the mouthpiece/valve to room air.
2. At end-tidal exhalation, connect subject to 100% O2 line or the demand valve and gas collection system.
3. Assure subject as test progresses.
4. Test for seven minutes or until exhaled N2% is less than 1.5% (varies slightly with equipment).
5. Close valve and disconnect subject.
6. Measure exhaled volume of test or record value if volume has been accumulated.
7. Analyze collected gas N2%.
8. Calculate FRC.

$$FRC = \frac{\%N2 \text{ final} \times \text{expired volume}}{\%N2 \text{ alveolar} - (75\%)}$$

i.e. N2 final = .08
V expired = 36 L

$$FRC = \frac{.08 * 36}{.75} = 3.840 \text{ L}$$

FRC - BOCY PLETHYSMOGRAPH

C. Body Plethysmograph

Equipment Preparation - Calibrate both transducers and check their operation. Turn on oscilloscope and its graphing method (photograph, storage oscilloscope).

Subject Preparation - The box may seem confining so a complete description of the test is necessary. Explain that the test involves normal breathing and then a short period of rapid panting against an obstruction.

1. Place subject in the box and have the subject breath through the mouthpiece to the outside.
2. Have subject breath normally for a short period.
3. At end-tidal exhalation, close shutter and instruct subject to pant rapidly.
4. Record slope $\left(\frac{\Delta P \text{ - airway}}{\Delta V \text{ - box converted from pres.}}\right)$ of panting effort.
5. Open shutter and instruct subject to rest.
6. Repeat as necessary for repeatable values.
7. Calculate FRC by corresponding slope angle to FRC on table.

$$FRC = \frac{970 = \left[\text{gas pressure in lungs (BP-H2O vapor pressure)}\right]}{\text{slope}\left(\frac{\Delta P}{\Delta V}\right)}$$

i.e. slope = 0.6

$$\frac{970}{0.6} = 1610$$

QUESTIONS - RESIDUAL VOLUME

1. Name three methods of residual volume determination.

2. An increase in residual volume is indicative of _____ _____ pulmonary disease.

3. Why is a body plethysmograph considered more accurate than Helium dilution or Nitrogen washout?

5. ARTERIAL BLOOD GASES

OBJECTIVES

- The learner shall draw an arterial blood sample from the radial or brachial artery.
- The learner shall analyze the arterial blood sample.
- Perform basic interpretation of the analyzed sample.

PERSPECTIVE

Since the advent of electrodes for gas pressure analysis of blood in the 1950's, arterial blood gases have become invaluable clinical parameters for evaluating pulmonary and acid-base status. Sampling from a high pressure arterial vascular system was initially considered hazardous and specimens were attained by physicians only. As the procedure became more frequently performed, its safety was realized and drawing was relegated to allied health personnel. Arterial blood gases (ABG) are now ordered and drawn for monitoring ventilator patients, in pulmonary function testing, gauging oxygen therapy, and generally assessing pulmonary and acid-base status. Although considered a safe procedure, it is necessary to have individuals well trained and periodically checked out in drawing technique.

Beyond knowing the technique of arterial puncture, respiratory care personnel must have thorough knowledge of arterial blood gas electrode performance and basic interpretation of blood gases. Unfortunately, the latter two subjects are beyond the scope of this manual.

ARTERIAL BLOOD GASES

Equipment Preparation - Obtain ice, cork, syringe, 21-25 gauge needle, heparin, towel, tape and lubricate the syringe with heparin.

Subject Preparation - Inform the patient of the procedure, particularly, its importance. Inform him/her that there may be some discomfort.

1. From the ability to assess precise location and strength of pulse, choose a site for puncture from the radial, brachial or femoral artery (in that order of preference).

2. If the radial site is chosen, perform an Allen test. Depress the radial and ulnar arteries for 10-20 seconds and have the subject make a fist, then release it. Release the radial compression and note if the blanched hand has a return of color. If the hand remains blanched, consider another site.

3. Site Preparation - Clean the area thoroughly with alcohol, betadine and soap, if necessary. Secure the limb or area with tape or an assistant, if necessary.

4. Puncture - Tell the subject when you are prepared. Check that the syringe is well lubricated and eject the remaining heparin. Enter the skin with the bevel up at a 40^{0}-60^{0} angle. After a flash of blood, allow the syringe to fill to at least two ml.

5. Probing - If the puncture is not immediately successful, careful probing may be necessary. One may withdraw <u>without</u> exiting the skin and re-advance towards the artery. This can be slowly re-attempted as tolerated.

6. Post Puncture Care - Withdraw the syringe and apply digital pressure for a minimum of three minutes. Cork the needle, mix the sample and place the sample on ice. Bandage or pressure pack the site.

QUESTIONS - ARTERIAL BLOOD GASES

1. Why is an Allen test performed prior to arterial puncture?

2. What gauge needle is appropriate for arterial puncture?

3. Post puncture digital compression should be for _____ minutes.

6. SINGLE BREATH DIFFUSION TESTING

OBJECTIVES

- The learner shall perform a single breath diffusion test on a subject.
- To calculate the individual's diffusion capacity from raw data.
- To determine normal value diffusion capacity for the subject and compare the obtained value to predicted. normal.

PERSPECTIVE

There are persons with normal lung function testing and normal hemoglobin that are hypoxemic at rest. During exercise the hypoxemia accentuates without CO2 retention. This group of individuals is a very small percent of the total number of persons with abnormal pulmonary function. An account for their abnormal pulmonary function is an increase in the alveolar capillary membrane or distance for gas diffusion. Diffusion testing identifies these persons, but diffusion defects or a false positivity is noted in tuberculosis, emphysema, lung resection and anemia where impairment is not actually at the alveolar capillary membrane. True diffusion defects are found in the pneumoconioses, sarioidosis and after inhalation of poisonous gases. Testing for diffusion defects involves inhaling a low concentration of carbon monoxide, holding that volume for 10 seconds and then exhaling the volume into a bag for analysis. Since the carbon monoxide binds to hemoglobin 210 times that of oxygen, the amount of CO exhaled is inversely related to the diffusion capacity. This is an atypical breathing pattern, but allows simple calculation and performance of a diffusion test.

DIFFUSION TESTING - SINGLE BREATH

Equipment Preparation - Calibrate and zero the helium and CO analyzers.

Subject Preparation - Explain that the procedure is short, but that there can be no leaks or rests. That the subject will take a deep breath, hold it for 10 seconds and blow it out.

1. Have the subject breath normally through a Rudolph valve - to room air.
2. Have the subject exhale completely to RV.
3. Open Rudolph valve to 0.3% CO - 10% helium mixture.
4. TAKE IN A DEEP BREATH - to TLC and HOLD IT.
5. HOLD IT - for 10 seconds.
6. BLOW IT ALL OUT.
7. Collect exhaled gas sample in empty DOUGLAS bag. Most systems reject an initial VD volume of 100-500 ml and collect then the alveolar volume.
8. OKAY, TAKE A REST.
9. Analyze the exhaled gas for CO, helium concentrations.
10. Calculate DLCO SB =

$$DLCO = \left(\frac{VA \times 60}{(PB-47)\ (10)}\right) * \quad Ln\left(\frac{FACO\ initial}{FACO\ initial}\right)$$

VA = inhaled vital capacity
Ln = natural log
FACO final = analyzed CO
FACO initial = initial CO (0.3%) * $\frac{FeHE}{FIHE}$

11. Repeat the test until repeatable values within 10% are obtained.
12. Compare to predicted.

QUESTIONS - SINGLE BREATH DIFFUSION TESTING

1. In which patients might a diffusion test be false positive for a true diffusion defect?

2. Describe the basic procedure for a single breath diffusion test.

3. A true diffusion defect occurs in _____.

7. STEADY STATE DIFFUSION TESTING

OBJECTIVES

- The learner shall perform a steady state diffusion test.
- Draw an arterial blood gas during the procedure.
- Collect exhaled gas during the procedure.
- The learner shall calculate steady state DLCO from raw data.
- Compare calculated steady state diffusion from the individual's predicted rate.

PERSPECTIVE

Steady state diffusion testing measures diffusion during a period of normal or exercise breathing; more typical situations for diffusion abnormalities than the single breath vital capacity maneuver. The testing is more involved and is invasive. Normal steady state DLCO is 18 ml CO/min/mmHg.

DIFFUSION - SS

Equipment Preparation - Douglas bag, CO analyzer, delta nitrogen analyzer, ABG kit.

Subject Preparation - Instruct the subject that normal breathing will be necessary through the mouthpiece for 5-6 minutes. Furthermore, near the end of the test an ABG sample must be taken.

1. Have the subject breath normally through a Rudolph valve open to room air.
2. Connect the inspiratory port to 0.2% CO gas.
3. Allow equilibrium by breathing the gas for 4 minutes.
4. Connect expiratory post to empty Douglas valve and collect gas for 2 minutes.
5. During the collection period, obtain an ABG sample.
6. At six minutes, take subject off mouthpiece and TAKE A REST.
7. Analyze collected gas sample for CO, CO2, O2.
8. Analyze ABG for pCO2.
9. Calculate DLCO SS = $\frac{\dot{V}CO\ (STPD)}{PACO}$

$$r = \frac{PaCO2 - PECO2}{PaCO2}$$

$$\dot{V}CO = \dot{V}E\ (FICO\left(\frac{FEN2}{FIN2}\right) - FECO)$$

$$PACO = \left(PB - 47\right)\left(\frac{FECO - rFICO}{1-r}\right)$$

10. Repeat.

QUESTIONS - STEADY STATE DIFFUSION TESTING

1. Normal steady state DLCO is _____ (include units).

2. Why may steady state diffusion be considered more accurate than single breath testing?

3. A disadvantage of steady state testing would be:

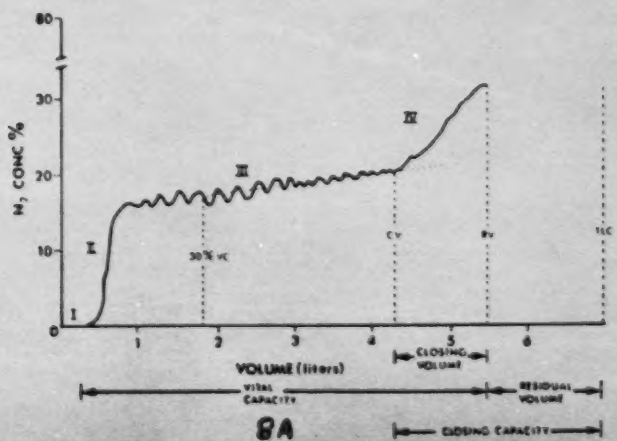
8. CLOSING VOLUME

OBJECTIVE

- To have the subject inhale to total lung capacity a 100% oxygen bolus and graphically record exhaled nitrogen percent with volume during a slow exhalation.
- Determine from the recording of N2 and volume: phases I, II, III, IV, closing volume, closing capacity, and delta nitrogen.
- Note abnormal phases or parameters indicating obstruction or uneven gas distribution.

PERSPECTIVE

A problem in the diagnosis of obstructive pulmonary disease has been the insensitivity of the available tests. The flow measurements discussed earlier can be late appearing in the disease, but do provide a valid, repeatable documentation of obstruction. A theory of the obstructive disease process is that it progresses from the small airways to a less reversible large airway obstruction. Closing volume, closing capacity and delta nitrogen attempt to measure that early small airways disease or uneven gas distribution. Closing volume is the portion of the inhaled vital capacity that does not freely communicate with the 100% oxygen and is measured as a volume of higher concentration nitrogen (phase IV). The phase IV, as a percent of the total vital capacity, defines the closing volume. Closing capacity is the closing volume added to the residual volume ascertained by another technique (section 4). Closing volume would normally be between 10-20%, while closing capacity would range from 20-40% with above normal ranges indicating small airway obstruction. Delta nitrogen is the change in nitrogen concentration from the point of 750 ml exhaled to 1250 ml exhaled. A delta nitrogen of more than 3% indicates an uneven distribution of gases in the lungs or air trapping.



8A

CLOSING VOLUME, DELTA NITROGEN

Equipment Preparation - X-Y recorder, delta nitrogen analyzer, 100% O2 source with demand valve or Rudolph valve set-up.

Subject Preparation - Inform the subject that one deep breath will be measured from complete exhalation to complete inhalation, hold, slow exhalation.

1. Flush system so that 100% O2 is up to the valve.
2. Have the subject breath normally through the valve open to room air. Turn on nitrogen analyzer with X-Y recorder.
3. Instruct the subject to BLOW IT ALL OUT. Exhale to residual volume.
4. Change the valve to the 100% O2 source. (Demand valve)
5. TAKE A DEEP BREATH (to total lung capacity).
6. At the top, EXHALE SLOWLY to COMPLETE EXHALATION.
7. At end exhalation, turn off the recorder and have the subject rest.
8. A pattern such as 8A should result.
9. Repeat at least two times until repeatable results are attained.

i.e.

Δ N2 from 750 to 1250 = 5%
CV = 900 ml
CC = 2400 ml
VC = 4000

CV% = 900/4000 = .225 or 22.5%

CC% = 2400/5500 = .436 or 43.6%

QUESTIONS - CLOSING VOLUME

1. Closing volume measurements are obtained to determine the degree of obstruction in the _____.

2. To measure closing volume, one inhales to total lung capacity a bolus of _____.

3. A delta Nitrogen of more than 3% indicates:

9. FLOW VOLUME LOOP

OBJECTIVES

- To have the subject perform a vital capacity for flow volume loop measurement.
- To record the maneuver on an X-Y recorder set for flow and volume.
- To determine from the recording: peak flow, midflow, FEV1, FEF .75 and pattern abnormalities.

PERSPECTIVE

The flow volume loop is a refinement of and addition to vital capacity and flow measurements. It allows a composite view on one pattern of flow and volume with one second intervals "ticked" off for time interval calculations. The flow volume loop analysis provides precise measurements of peak flow, FEF .25, FEF .50 ...and any other partition of the vital capacity with a potential visualization of the small airways or early airway disease. This end of exhalation is effort independent. The flow volume loop can more easily acknowledge malingering. Since the loop can, also, graph the inspiratory arm, it can provide evidence for upper airway intrathoracic and extrathoracic lesions.

FLOW-VOLUME LOOP

Equipment Preparation - An X-Y recorder to plot flow vs. volume interphased with a volume time measuring device (i.e. Med-Science system). The recorder must be correctly calibrated with the volume/time measuring device.

Subject Preparation - Instruct the patient that this procedure involves 3 to 5 maximum efforts of their deepest breath exhaled rapidly and followed by a maximum inhalation.

1. Have volume in the spirometer or wedge and have the recorder in an appropriate "start" position that will allow the complete pattern to be completed on the recording paper.

2. Check that: recorder is for volume and flow, system is on a correct calibration range, system is on and ready to record. (a remote recorder button may be used).

3. Have patient take AS DEEP A BREATH AS POSSIBLE and put mouthpiece in his/her mouth (noseclips on).

4. BLOW into the machine as deep, fast and completely as possible.

5. Now, TAKE IN A DEEP BREATH

6. Turn off the recorder and examine the pattern. Determine whether it is complete and of maximum effort.

7. Repeat the procedure until at least two loops are maximum and comparable within 5%.

i.e.

A. Peak, mid and more defined flows. From there, "start" baseline. Take the peak vertical distance or vertical distances at 50% VC - mid or another increment and multiply it by calibration conversion values (Figure 9A).

   i.e. six vertical boxes x 60 L/min/box = 360 LPM

B. VC, FEV1, FEV2
   Take the horizontal distance from the start position for the complete breath - VC or the "tics" for FEV1, FEV2,...and multiply by calibration-conversion value.

   i.e. 8.5 boxes x 500ml/box = 4250 ml

C. Patient independent portion - examine the slope of end exhalation for evidence of slow (small airway) closure (a steep vs. a long ramp).

D. Pattern appearance - does the pattern have a distinct peak flow or does it have the appearance of upper airway lesions.

QUESTIONS - FLOW VOLUME LOOP

1. Flow volume loops allow precise measurement of _____ and _____.

2. A flow volume loop has a distinct pattern for _____ _____ obstruction, even distinguishing whether the lesion is _____ thoracic or _____ thoracic.

3. A flow volume loop can be divided into effort-_____ and effort-_____ portions.

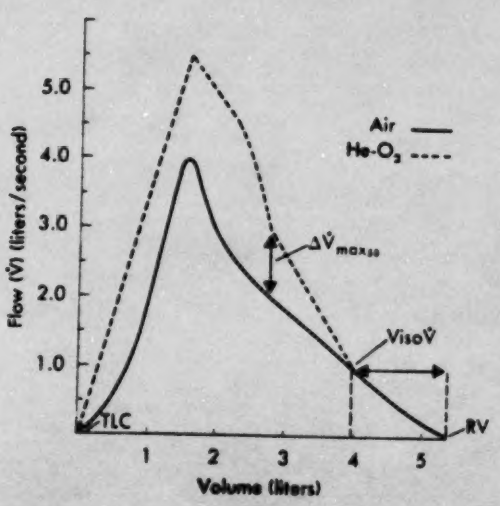
10. VOLUMES OF ISOFLOW

OBJECTIVES

- To perform a flow volume loop.
- Repeat a flow volume loop after five deep inhalations of 80% Helium - 20% Oxygen.
- Calculate the volumes of isoflow and the increase in Vmax 50.

PERSPECTIVE

Volumes of isoflow is a test to differentiate whether the obstruction is of central or peripheral airway origin. By inhaling a 80% Helium-20% Oxygen mixture, one's exhaled flow rate should increase over the effort dependent portion of the flow volume loop. That increase, due to the decreased density of Helium, can be measured and quantified as a percent increase in the midflow or FEF .50. The point of the curve where effort independence occurs can be identified by overlaying an air-flow volume loop and marking where the curves coincide. The subsequent volume exhaled after the curves coincide is the volume of isoflow that would normally be 20% of the vital capacity. Increase in the volume of isoflow indicates small airway disease or peripheral obstruction. If the increase in mid-flow after breathing the Helium mixture is reduced or absent, this, also, indicates small airway obstruction. The tests are easily performed and are most sensitive parameters for small airway obstruction, but are subject to variability.



VOLUMES OF ISOFLOW

Equipment Preparation - Obtain a tank of 80% HE - 20% 02 connected to a demand valve or run a flowmeter into a Douglas bag.

Subject Preparation - The instruction is identical to the instruction for flow-volume loops.

1. Perform a flow-volume loop as in Section 9. Repeat twice and measure Vmax50.
2. Connect the demand valve or HE-02 mixture in the Douglas bag to the inspiratory line of the patient.
3. Have the subject breathe the mixture for 5 minutes or three slow vital capacities.
4. Repeat the flow volume loop with the mixture as the inspiratory gas.
5. Repeat the procedure to obtain repeatable values.
6. Calculations.
   a. Determine the flow rate at 50% of VC with the mixture and determine the increase in $\dot{V}max50$.

$$\Delta \dot{V}max50 = \frac{\dot{V}max50He - \dot{V}max50\ air}{\dot{V}max50\ air} \times 100$$

   b. If possible, overlay the He flow-volume loop over the air flow-volume loop and identify the point of curve convergence. Calculate the % of VC at that point.

i.e. $\dot{V}max\ He = 160$ L/min
$\dot{V}max\ air = 100$ L/min

$$\dot{V}max50 = \frac{160-100}{100} \times .6 \text{ or } 60\%$$

i.e. Volume at point of convergence = 4000 ml
Vital Capacity = 5000 ml

5000-4000 = 1000
1000/5000 = .2 = 20%

QUESTIONS - VOLUMES OF ISOFLOW

1. The gases usually used in volumes of isoflow are _____% _____ and _____% _____.

2. The volume of isoflow is normally less than _____% of one's vital capacity.

3. One overlays an air _____ over the He-02 _____ To identify the point of isoflow.

11. MECHANICS TESTING

OBJECTIVES

- To test and calculate mechanics parameters on a ventilator patient.
- To test and calculate airway resistance on a subject in a pulmonary function laboratory.

PERSPECTIVE

The opposing mechanical forces of tendency for thoracic expansion and lung collapse are balanced and alter slightly to create gas movement into and out of the lungs. The measurement of these opposing forces is termed compliance and defined as change in volume/change in pressure (static airway-lung pressure). An increase in compliance is noted in emphysema where the tendency for lung collapse, supposedly from elastin destruction, is diminished. Compliance is decreased in atelectasis, ARDS, fibrosis, obesity... in which there is a stronger tendency towards lung collapse. Although lung and chest wall compliance can be measured with esophageal balloons in a pulmonary function laboratory, it is infrequently performed. Monitoring serial compliance measurements on ventilator patients has become an invaluable procedure for following changing pathology. Normal compliance is 0.1L/cmH2O, but reductions to less than .010 have been noted in severe ARDS.

Resistance is a measure of airway mechanics that is quantified as a change in pressure/change in flow standardized at 30 LPM or 0.5LPS. Airway resistance can be markedly increased in asthma It may be increased in emphysema and chronic bronchitis relative to the degree of obstruction. The testing is most often performed in a body plethysmograph where pressure changes in the airway are measured during panting. The flow during panting is measured by a pneumotachometer. When the test is completed near FRC, normal values should be from 0.6 - 2.4 cmH2O/LPS.

Another easily performed test of pulmonary mechanics is the negative inspiratory force (NIF). It is frequently used to determine respiratory drive adequacy for possible weaning from mechanical ventilation. The procedure involves requesting the subject inhale against an obstruction and measuring with a manometer the negative pressure generated. A normal individual should attain -80 to-100 cmH2O, while -20 cmH2O is considered adequate to wean from mechanical ventilation

MECHANICS

Compliance - on ventilator patients

Equipment Preparation - Patient receiving mechanical ventilation on A-C mode.

Subject Preparation - Explain to patient that he/she will be holding their breath x 1.

1. Observe ventilatory pattern, pressure, volume on ventilator, PEEP if applied.
2. Record VT.
3. During inhalation, occlude the exhalation valve or inhalation tubing.
4. In the subsequent exhalation, observe and record the plateau pressure.
5. Release occlusion.
6. Calculate compliance

$$= \frac{VT - (3 \times PEI)}{PEI - 0 \text{ or PEEP pressure if applicable}}$$

Resistance

Equipment Preparation - Same as FRC-BP, but pneumotach is in line.

Subject Preparation - Same as FRC-BP.

1. Have the subject breath normally in the plethysmograph.
2. Instruct the subject to breath deep and fast.
3. Photograph, graph or measure the slope of $\dot{V}$ (flow) with Pp (pressure in the body plethysmograph).
4. The shutter in the moughpiece is closed.
5. Photograph, graph or measure PA (airway pressure with Pp). *Lung volume FRC measured here.
6. Calculate RAW = slope of $\frac{PA/Pp}{V/Pp}$

Procedure only
continued

NIF

Equipment Preparation - Obtain manometer with negative pressure graduations, a T-piece that allows manometer connection and occlusion port.

Subject Preparation - Inform patient that you desire an inspiratory effort for only one breath against an occlusion.

1. Connect patient's airway to T-piece (nose-clips and mouthpiece that is air tight with system if patient isn't intubated).
2. Occlude port.
3. Instruct patient to inhale.
4. Observe NIF attained.
5. Release occlusion.
6. Repeat as needed for best effort.

QUESTIONS - LUNG MECHANICS

1. Compliance is defined as delta _____/delta _____.

2. Compliance is increased in _____ and would be decreased in _____.

3. Resistance is defined as delta _____/_____ at a standard of _____L/min.

12. p50

OBJECTIVES

- The learner will obtain a 20 ml arterial or venous blood sample.
- The learner will calculate an approximate p50 value.
- Perform tonometry at several calculated pO2 levels and analyze the samples for saturation.
- Construct the subject's dissociation curve and determine p50.

PERSPECTIVE

The p50 is the partial pressure of oxygen in the blood at which 50% of the hemoglobin is saturated. The determination of p50 has been advocated in critical care patients that have received infusions of stored or banked blood. Stored blood has been shown to have a decreased 2,3 DPG in direct relation to the time stored. This decreased 2,3 DPG may left shift the individuals oxygen dissociation curve resulting in a stronger O2-Hemoglobin bond. This makes oxygen less available to the tissues. A compensatory right shift, as measured by an increased p50, is present in anemia and chronic hypoxemia; therefore, oxygen is more available to the tissues with a weaker O2-Hemoglobin bond. Although the position of the dissociation curve (p50) has received attention in the literature, p50 measurements for the above have not attained the relevence of routine clinical monitoring. A shift in p50 is present in several congenital abnormal hemoglobins. Since p50 can be measured or approximated quite easily, it may assist in the diagnosis of abnormal hemoblobinemia from a presenting polycythemia vera.

p50 can be measured by dividing a blood sample into aliquots and performing tonometry at several decreasing FIO2 concentrations. A graphing of the individual's dissociation curve will allow interpolation of the precise p50. A venous sample pO2 and saturation can be used in one of several equations to approximate quite close the p50.

p50

Equipment Preparation - A calibrated ABG analyzer, a tonometer with the ability to titrate varying FIO2 concentrations, a CO oximeter.

Subject Preparation - Obtain a venous blood sample.

A. Approximated technique - Analyze the venous blood in an ABG analyzer and CO-oximeter

$$p50 = 26.6 \times \frac{pO2}{pO2\ sat.}$$

pO2 sat. is the pO2 on the standard curve corresponding to the measured O2 sat. from the CO-oximeter.

i.e. $26.6 \times \frac{40}{44} = 24.2$

B. Calculated technique

1. Divide the sample into six aliquots of about equal size.
2. Do tonometry of each aliquot at an FIO2 that calculates to a pO2 of between 15 and 40.
3. Analyze each sample for pO2 and O2 saturation.
4. Record the sample points on a O2 saturation/PO2 graph.
5. Construct the person's dissociation curve by connecting the points.
6. Determine p50 from curve by interpolation.

i.e.

ALIQUOTS	pO2	O2 SATURATION
A	18	35
B	22	40
C	27	48
D	35	54
E	40	60
F	42	61

p50 = 27 + (2/6 x 8)
= 29.5

QUESTIONS - p50

1. p50 is defined as the partial pressure at which:

2. Name three factors that would increase the p50.

3. An estimate of p50 can be calculated from the saturation and partial pressure of a sample of _____ _____.

13. FICK CARDIAC OUTPUT AND RESPIRATORY QUOTIENT

OBJECTIVES

- To collect a normally breathing subject's three minute exhaled gas sample.
- Analyze the PaO2 and PaCO2 of the exhaled gas sample.
- Calculate oxygen uptake per minute and CO2 output per minute.
- Analyze an arterial and mixed venous blood sample from the subject.
- Calculate Cardiac Output and Respiratory Quotient for the subject.

PERSPECTIVE

One can collect exhaled gas from a normally breathing subject permitting analysis of PO2 and PCO2 of the sample. Oxygen uptake and Carbon Dioxide output can then be calculated if the volume of exhaled gas was, also, measured. Furthermore, from the oxygen uptake, cardiac output by the Fick method can be calculated when mixed venous PO2, arterial PO2 and hemoglobin are known. The cardiac output can then be compared and verified with thermodilution and dye techniques. By whichever technique, cardiac output may be of value in quantifying high or low cardiac output states, measuring the effect of drug therapy or following a specific pathology. The raw values of O2 uptake and CO2 output can be divided to calculate the respiratory quotient (R.Q.) which would normally be 0.8. The R.Q. may have application in quantifying metabolic status.

CARDIAC OUTPUT (Fick) AND R. Q.

Equipment Preparation - Obtain a Rudolph valve connected to a collection bag (Douglas) and a respirometer (Wright or Drager) to measure the exhaled volume.

Subject Preparation - For C.O. determination (Fick) a right heart catheterization must be completed (in a cath. lab) for mixed venous gas O2 sampling during the procedure. An arterial sample should, also, be obtained. Tell the subject that the breathing test is simple and involves normal breathing.

1. Have the subject breath normally through the mouthpiece open to room air.
2. Simultaneously start the timer and turn the valve to collect all exhaled gas.
3. During the three minute gas collection period, the mixed venous blood sample should be drawn.
4. At 3 minutes, stop gas collection.
5. Analyze the exhaled gas sample for pO2, pCO2 using the ratio of Cal gas to obtain percent exhaled gas.

$$\frac{\text{Cal Gas}}{\frac{.10}{(PB-47}\ \%\ \text{Cal gas)}} \times \frac{\text{Sample Gas}}{\frac{X}{121}}$$

X = % of exhaled O2
121 = pO2 of exhaled gas

$$\left[\dot{V}E\ (.2093 - X) / 3\right] * \left[\text{STP correction factor}\right] = \text{O2 uptake (ml/min)}$$

6. Measure total exhaled volume.

$$\text{C.O.} = \frac{\text{O2 uptake}}{10\ \left[\text{A-V content difference in vol \%}\right]}$$

$$\text{R.Q.} = \frac{\text{O2 uptake}}{\text{CO2 output}}$$

$$\text{CO2 output} = (\dot{V}E/3) * (\%\ \text{of CO2 from analysis})$$

QUESTIONS - CARDIAC OUTPUT FICK METHOD

1. To calculate cardiac output by the Fick method one must have a mixed venous pO2, an arterial pO2 and a measured _____ _____.

2. State another method of cardiac output determination.

3. What is the value for normal respiratory quotient and how is it defined?

14. VD/VT

OBJECTIVES

- Collect an exhaled gas sample from a rudolph valve or exhalation valve of a patient on mechanical ventilation.
- Analyze the pCO2 of the exhaled gas sample.
- Calculate the VD/VT from the exhaled PCO2 and PaCO2 (from ABG's drawn at the time of the gas collection).
- Correct the VD/VT by subtracted the tubing compliance factor if the patient was receiving mechanical ventilation.

PERSPECTIVE

The measurement of deadspace volume (VD)/tidal volume (VT) had been regularly used for the assessment of cardiopulmonary dysfunction in the 1960's. Although exhaled gas sampling and analysis are easily performed, arterial blood gases have supplanted the need for the procedure. Recently, the distinction of differentiating shunt, deadspace and/or V/D mismatching has warranted the analysis of exhaled gas, even on a breath to breath basis. Although exhaled CO2 monitors are being utilized, a pooled three minute exhaled CO2 collection procedure will be described. With an ABG being performed at the time of collection, VD/VT can be calculated. A correction must be made for compressed gas volume if the patient is receiving mechanical ventilation. Normally, VD/VT is 0.3 or 30% and values above 30% are considered abnormal or indicating deadspace ventilation. Over 60% often necessitates mechanical ventilation. The recent advent of high frequency ventilation with the concept of increased diffusivity probably alters the theory of VD/VT. Measurement of VD/VT in high frequency ventilation will prove interesting. Generally, serial VD/VT measurments are easily performed and provide additional information about a changing pulmonary pathology.

VD/VT

Equipment Preparation - Obtain a deflated Douglas bag or any non-permeable collection system and an ABG sampling kit.

Subject Preparation - Preparation must include that of ABG sampling. Furthermore, explain that exhaled gas is to be collected and there will be no direct effects.

1. Have the subject breathing their normal ventilatory pattern through a Rudolph valve. The subject may be on mechanical ventilation, but not with a high flow system.
2. Connect the Douglas bag to the exhalation port of the Rudolph valve or ventilator circuit.
3. Allow the bag to fill for three minutes. One minute would suffice if ventilatory volumes and patterns are stable.
4. Disconnect the system and close the gas sample from contamination by room air.
5. Ideally, obtain an ABG sample during gas collection, but ABG sampling may be completed before or after collection in a subject with stable ventilatory volumes and rates.
6. Analyze the gas sample - The procedure varies with each analyzer, but often patterns the method of analyzing calibration gases.
7. Analyze ABG sample.
8. Calculate VD/VT

$$VD/VT = \frac{PaCO2 - PeCO2}{PaCO2}$$

e = expired
a = arterial

For a ventilator patient:

$$VD/VT = \frac{PaCO2 - P_{E}CO2 \text{ corrected}}{PaCO2}$$

$$P_{E}CO2 \text{ corrected} = \frac{VT}{VT - (P_{EI} \times 3)} \times P_{E}CO2 \text{ measured}$$

Example

$PeCO_2 = 20 \quad paCO_2 = 40$

$P_{EI} = 30 \quad VT = 800$

$$P_{E}CO_2 \text{ (corrected)} = \frac{800}{710} \times 20$$

$$= 22.4$$

$$VD/VT = \frac{40-22.4}{40} = .44 \text{ or } 44\%$$

QUESTIONS - VD/VT RATIOS

1. Normally, VD/VT is _____ or _____ percent.

2. The effectiveness of _____ defies the basic concept of VD/VT ratios.

3. The calculation of a VD/VT ratio requires the measurement of what two parameters?

15. OXYGEN AND CARBON DIOXIDE RESPONSE

OBJECTIVES

- Administer controlled and fixed oxygen and carbon dioxide gas concentrations.
- Monitor exhaled minute volumes during fixed gas concentration administration.
- Graph the oxygen and carbon dioxide response curves for the subject tested.

PERSPECTIVE

Why we breath or our ventilatory drive is partially or completely controlled by PaCO2 and PaO2 levels. Hypoxic control is primarily through the peripheral chemoreceptors in the carotid bodies and aortic arch. These receptors stimulate an exponential increase in ventilation from a PaO2 of 60 to 40 mmHg. Carbon dioxide pressures stimulate ventilation in a chemosensitive region of the medulla (which changes pH) resulting in a linear increase in ventilation of 3 LPM for each 1 mmHg increase in PaCO2. CO2 response has been found to be depressed or absent in some patients with emphysema. An absence or depression of O2 response has been found in athletes, persons residing in high altitudes and after administration of some medications. Individual variations can be measured by graphing ventilatory changes after careful administration of decreasing increments of FIO2 and increasing increments of FICO2. This testing should be carefully controlled and monitored by a physician.

CO2 AND O2 RESPONSE CURVES
(Open Circuit)

*Under physician supervision

CO2 response

Equipment Preparation - Obtain a pressure transducer manometer timed with shutter, CO2 tanks gases at 3, 5, 7% with 21% O2, and respirometer

Subject Preparation - Inform the patient to breath as normally as possible, but that he/she may feel a need to breath faster or slower.

Open Circuit Technique

1. Have the patient breathing normally through the mouthpiece with the pressure transducer in line and respirometer on the exhalation port of the valve.

2. Record minute volume and P0.1 (Section 16). (Exhaled CO2 and ABG's may, also, be measured).

3. Administer 3.0% CO2 and repeat measurements from 2 after 5-7" equilibrium.

4. Administer 5.0% CO2 and repeat.

5. Administer 5.0% CO2 and repeat.

6. Graph PICO2 vs. ventilation
   Graph PICO2 vs. Pa.1
   Graph PICO2 vs. PaCO2
   Graph PICO2 vs. PECO2

QUESTIONS - CO2 AND O2 RESPONSE CURVES

1. Hypoxic control of ventilation is localized in the:

2. A deficiency in CO2 response has been noted in individuals with _____.

3. Which gas more finely controls ventilation?

16. OCCLUSION PRESSURES

OBJECTIVES

- Have the subject ventilate normally through a mouthpiece-valve system.
- During normal ventilation, occlude the mouthpiece during exhalation and record pressure changes on an X-Y recorder and/or oscilloscope.
- Record the PO.1 for the subsequent inhalation and repeat as necessary.

PERSPECTIVE

Occlusion pressure is a measure of the ventilatory drive that is entirely under neurologic control. It is a pressure measured just prior to gas movement on inhalation, therefore, it is not a measure of respiratory muscle status or airway resistance. If a shutter is closed immediately before a normal inhalation, the pressure change at 100 milliseconds is of neurologic control or effort. This pressure change can be used as a quantity in CO2 or O2 response curves and particularly in serial measurements on ventilator patients with neurological deficits.

OCCLUSION PRESSURES

Equipment Preparation - A system should be set up with a pressure vs. time oscilloscope or X-Y recorder, a pressure transducer in line with the airway, and a shutter on the inspiratory arm of the Rudolph valve distal to the manometer.

Subject Preparation - Inform the patient to breath as normally as possible and that there will be short interruptions during inhalation.

1. Have the subject breath normally through the mouthpiece-valve system.
2. Occlude the shutter during exhalation.
3. Have the X-Y recorder and/or oscilloscope on.
4. Record P0.1 for the subsequent inhalation from the pressure graph.
5. Repeat as necessary.

QUESTIONS - OCCLUSION PRESSURES

1. Occlusion pressure measures ventilatory drive entirely under _____ control.

2. Occlusion pressure is measured _____ milliseconds after occlusion.

3. Serial occlusion pressure measurements may be helpful in monitoring ventilator patients with:

17. COMPUTERIZATION

OBJECTIVES

- The learner shall input pulmonary function software into the computer system.
- Input the requested values for the software package and receive a hardcopy of the parameters calculated.

PERSPECTIVE

This section merely overviews an expanding use of microprocessing in Pulmonary Function and Respiratory Therapy. The calculations of Pulmonary Function Testing are often lengthy and subject to human error in calculation and/or transcription. Computers and related programs can have pulmonary function parameters manually inputed or integrated with the measuring device simultaneously. The calculations can then be accurately, rapidly performed and printed in whatever format desired. Modifications of regression formulas can be completed by listing, altering and saving the program. Software packaging is available with any computer system or can be easily programmed. Furthermore, with a system intact, files of all tests completed can be stored on tape or disc without great additional cost.

COMPUTERIZATION

Equipment Preparation - The preparation will vary with machine and program to be used.

Subject Preparation - The subject should be informed that calculations will be performed on the computer.

1. Assure all connections to interphasing input and output devices.
2. Turn unit and components on.
3. Follow initialization commands, usually brief identification commands if on a microcomputer; but more elaborate commands are required on larger time sharing systems.
4. Input the desired program. Again, a brief command for microcomputer and more elaborate command on line with a time-sharing system.
5. Await feed in time.
6. Depending on the package/program in use, BP, date, patient's name, etc. may be required.
7. Begin P. F. testing - input or interphase P. F. parameters as determined.
8. Follow the program instructions: output should be formatted on the printer when input information has been entered.

QUESTIONS - COMPUTERIZATION

1. A standardized program of pulmonary function calculations can be termed a _____-ware package.

2. What two types of errors does computerization avoid?

3. A formatted _____ is produced almost simultaneously after raw parameters are entered.

18. ALLERGEN CHALLENGING

OBJECTIVES

- The learner shall administer specific doses, under supervision of the attending physician, of an aerosolized Methylcholine, Histamine or suspected allergen.
- The learner shall monitor the effects of the challenge by having the subject perform a flow volume loop before and after the specific doses.
- The learner shall know how to treat the effects of the challenge.

PERSPECTIVE

In the classification and possible selective therapy for asthma, it has been helpful to determine whether the site of airway constriction is central or peripheral. That is, constriction can tend to be upper airway (more extrathoracic) or lower airway (more intrathoracic) in response to a general or specific allergen. A lower airway reaction to allergen involves mast cell degranulation with Histamine release and subsequent bronchoconstriction. The degree of lower airway reactivity can be quantified and specified by the careful administration of a suspect allergen, methylcholine, or histamine. A positive response is measured after each dose of challenge by a decrease in pulmonary function preset before testing; i.e. a 20% loss in FVC, a 50% loss in isoflow volume. When a positive response is achieved, if achieved in lower airway disease, the number of doses is recorded as well as decline in pulmonary function. When the response is attained, atropine is administered to dilate the constriction. Since the response may be strong, a physician should be available for IM administration of epinephrine.

ALLERGEN CHALLENGE

Equipment Preparation - Nebulizer with lab standardized dose or dose sequence of Methylcholine (a suspected allergen in a baggie), a flow-volume loop apparatus or vitalograph.

Subject Preparation - Instruct subject that each set of inhalations will be followed by a P.F. test and that subjective impressions should be reported.

1. Perform a baseline FEV1 (MEF 50% or volumes Isoflow may be used).

2. Have the subject take five inspiratory capacities of the aerosolized challenge or suspected allergen.

3. At three minutes, repeat the post inhalation pulmonary function test.

4. Determine if there has been a 20% or greater drop in the pulmonary function test (FEV1). If not, repeat the challenge.

5. After a + response, record the number of inhalations administered.

6. After a positive response, repeat the pulmonary function test each three minutes for 15 minutes. If the test is not 90% of baseline at the end of 15 minutes, administer a bronchodilator (atropine bronchosol).

*7. If FEV1 remains decreased and subjective dyspnea is present, contact an available physician.

Example

TIME		FEVL	
0800	Baseline	3000	(100%)
0810	Post first set of inhalations	2900	(96%)
0815	Post second set of inhalations	2300	(77%)
0820	Challenges stopped		
0823		2350	(78%)
0826		2500	(83%)
0829		2850	(95%)
0832		2850	(95%)
0835		2900	(96%)

QUESTIONS - ALLERGEN TESTING

1. Allergen testing can assist in localizing the _____ _____.

2. What percent of drop in FEV1 is considered a positive response in allergen testing?

3. Since allergen testing can result in a marked response, administration of _____ by a physician may be necessary.

19. SLEEP APNEA STUDIES

OBJECTIVES

- To assist the physician in sleep apnea studies.

PERSPECTIVE

Hypoventilation and/or apnea during sleep has an undetermined, but probably significant prevalence in the population. The condition has resulted in cor pulmonale and even cardiopulmonary arrest. Testing for sleep apnea requires a regimen of simultaneous procedures while the subject is sleeping. The testing is extensive and direct physician supervision is necessary, but technicians are utilized for several aspects of the studies. Testing may include all or some of the following:

1. EEG - for sleep staging
2. Airflow Transfucers - usually on the nose or mouth to note upper airway obstruction
3. Arterial Lines - to monitor changes in arterial blood gases and/or arterial pressures
4. Esophageal Balloon - to measure intrapleural pressure or lack thereof in central apnea
5. EKG - for arrhythmia detection, bradycardia, tachycardia
6. Ear Oximeter - to observe on a continuous basis changes in arterial saturation
7. Transcutaneous O2 Monitor - to monitor changes in pO2 on a continuous basis
8. X-Y Recorders - to graphically record any or all parameters monitored
9. Swan Ganz Monitor - to monitor changes in pulmonary artery pressures and/or mixed venous O2

Studies can be performed over the entire night (prolonged) or for a portion of the day if the subject can fall asleep easily. Falling asleep easily is usually not a problem.

SLEEP APNEA STUDIES

Equipment Preparation - Calibration of all equipment to be used in the regimen is necessary. Recording sheets should be prepared.

Subject Preparation - The subject must have the studies thoroughly described. If day testing is to be completed, the individual may be instructed to remain awake the night before.

Procedure - Will vary with the particular laboratory.

QUESTIONS - SLEEP APNEA STUDIES

1. The prevalence of persons with sleep apneic periods is _____ _____.

2. Name 5 types of testing performed in a sleep apnea laboratory.

3. An esophageal balloon is used to measure _____ pressure.

20. PULMONARY STRESS TESTING

OBJECTIVES

- Assist during pulmonary stress testing in any of the following: describing and monitoring graded exercise on a treadmill or ergometer, EKG, ABG's, collecting and measuring exhaled ventilation and volumes, monitoring exhaled CO_2, and vital signs.

- Perform calculations on testing results to obtain: VD/VT, $P(A-a)O_2$, O_2 uptake, CO_2 output, MV.

PERSPECTIVE

The cardiac stress test has evolved as an accepted evaluation technique for associating angina and ST segment depression with myocardial ischemia. Although not as widely accepted, the pulmonary stress test has a value in evaluating pulmonary reserve by measuring pulmonary parameters during exercise. Both stress tests have their diagnostic value because of the exercise induced, but require particular attention to possible untoward effects during the procedure. A physician must be in attendance and from one to four technicians may be necessary. Basically, an exercise protocol on ergometer or treadmill is graded and progressive with stabilization for 3-5 minutes at each level. Monitoring may include several or all of the following: EKG, HR, BP, f, VT, MV, O_2 uptake, CO_2 output, pO_2, pCO_2, pH. The testing is halted if 85% of maximum HR is reached or patient response requires halting the test.

PULMONARY STRESS TESTING

Equipment Preparation - Depending on the regimen of tests in use, preparation will involve the specifics for those tests. Records and graphing must be accurately kept of the procedure(s). Defibrillator, manual resusitator with oxygen and intubation equipment should be available and checked out.

Subject Preparation - The entire procedure(s) should be thoroughly explained, including the length and extent of the stress. Subjective impressions must be sought.

Procedure - Will vary according tc the regimen utilized. Must be under physician supervision.

QUESTIONS - PULMONARY STRESS TESTING

1. A stress test is stopped when _____ percent of a predicted maximal heart rate or exhaustion occurs.

2. The stress is usually performed on a _____ _____ or cycle _____.

3. Which exhaled gases are monitored in pulmonary stress testing?

ANSWERS TO SECTION QUESTIONS

SECTION	ANSWERS
1.	1. Hutchinson 2. Over 80% 3. Three
2.	1. Obstructive 2. FEV1/VC 3. It may be a more sensitive indicator of obstructive impairment
3.	1. 75% 2. Inspiratory Capacity, Expiratory Reserve Volume, Tidal Volume 3. End exhalation of the Tidal Volume
4.	1. Helium Dilution, Nitrogen Washout, Body Plethysmography 2. Obstructive 3. It measures total thoracic gas volume
5.	1. To assess adequate collateral circulation 2. From 21 to 25 3. At least three
6.	1. TB, Emphysema, Pulmonary Resection, Anemia 2. One exhales to RV then inhales rapidly to TLC, holds it for 10 seconds and then exhales into the collection bag. 3. Pneumoconiosis, Sarcoid and inhalation of a poisonous gas
7.	1. 18 ml CO/min/mmHg 2. It involves normal breathing, not the artificial vital capacity maneuver 3. It is invasive and may include stress.
8.	1. Samll airways 2. 100% oxygen 3. Uneuen gas distribution or air trapping

ANSWERS TO SECTION QUESTIONS
(continued)

9.
1. Peak flow, midflow
2. Early airway, intra, extra
3. Dependent, independent

10.
1. 80% Helium, 20% Oxygen
2. 20%
3. Flow volume loop, flow volume loop

11.
1. Volume, pressure
2. Emphysema, ARDS or fibrosis
3. Volume, flow, 30

12.
1. 50% of the hemoglobin is saturated
2. Increase in 2, 3 DPG, acidosis, hypercarbia, increase in temperature
3. Venous blood

13.
1. Hemoglobin
2. Dye dilution or thermodilution
3. 0.8, CO2 output/O2 uptake

14.
1. 0.3 or 30%
2. High frequency ventilation
3. PaCO2, PECO2

15.
1. Carotid bodies and Aortic Arch or Pheripheral Chemoreceptors
2. COPD
3. CO2

16.
1. Neurologic
2. 100
3. Neurologic deficits

17.
1. Soft
2. Calculation, transcription
3. Print-out

ANSWERS TO SECTION QUESTIONS
(continued)

18.

1. Area of reactivity
2. 20% loss of VC or 50% loss of isoflow volume
3. Epinephrine

19.

1. Unknown, but probably significant
2. EEG, Airflow, Arterial Pressures, Intrapleural, EKG, Oximetry, Hemodynamic, TCO2
3. Intrapleural

20.

1. 85%
2. Treadmill, Ergometer
3. CO2, O2

APPENDIX

			NORMAL VALUES
Vital Capacity (ml)	Males	48.1xH - 20.0xA - 2810	Over 80% of predicted
	Females	40.4xH - 22.0xA - 2350	
FEV_1 / FVC			Over 70%
$FEV_{0.5}$ / FVC			Over 55%
FEF 200-1200 (L/sec)	Males	.277xH - .047xA +2.01	Over 80% of predicted
	Females	.368xH - .026xA -2.53	
FEF 25-75% (L/sec)	Males	.119xH- .045xA +2.51	Over 80% of predicted
	Females	.152xH- .030xA +0.55	
Inspiratory Capacity	0.75 x Vital Capacity		
Expiratory Reserve Volume	0.25 x Vital Capacity		
Tidal Volume	Radford Nomogram		500 ml
Residual Volume	Males	57.8xH + 16.0A -40xW - 4240	
	Females	55.9xH - 30.0xW - 4910	
Arterial Blood Gases	p_aO2 (mmHg)		95-100
	p_aCO2 (mmHg)		35-45
	pH		7.35-7.45
	Oxygen Saturation		97%
	HCO_3^- (meq/L)		22-26
Diffusion - Single Breath (ml/min/mmHg)			25
Steady State (ml/min/mmHg)			18

APPENDIX

	Normal Values
Closing Volume / Vital Capacity	5-15%
Closing Capacity / Total Lung Capacity	20-35%
Delta Nitrogen 750-1250	less than 5%
Volumes of Isoflow (5)	
0.450xA + 4.69	10-25%
Mechanics	
Compliance	0.1 L/cm H20
Resistance	0.6 - 2.4 cm H20/L/sec
p50	27 mmHg
Cardiac Output	4-6 L/min.
Respiratory Quotient	0.8
VD/VT	0.3

Temperature Conversion Factors

20 degrees C.	to	37 degrees C.	-	1.102
20 degrees C.	to	0 degrees C.	-	.907

REFERENCES

- Handbook of Physiology: Respiration. Editors: Fenn WO, Rahn H. Washington D.C., 1964, Waverly Press Inc.

- Cherniak RM: Pulmonary Function Testing. Philadelphia, Pennsylvania 1977, W.B. Saunders.

- Fraser L, Genda R, McKeever R, Richardson D: A Vocational Educator's Guide to Competency Based Personalized Instruction. Minnesota 1976, H.O.P.E. Project.

- Ruppel G: Manual of Pulmonary Function Testing. St. Louis, Missouri 1979, C.V. Mosby Company.

- Pace WR: Pulmonary Physiology. Philadelphia, Pennsylvania 1972, F.A. Davis Company.

- Chai H, Farr RS, Froehlich LA, et al: Standardization of bronchial challenge procedures. J Allergy Immunol 1975:56:323-7.

- Craig KC, Pierson DJ: Expired gas collection for dead space calculations: A comparison of 2 methods. Respiratory Care 24:435, 1979.

- Interviews with Pulmonary Function Laboratory Personnel in the Twin Cities area-Minneapolis and St. Paul Minnesota.